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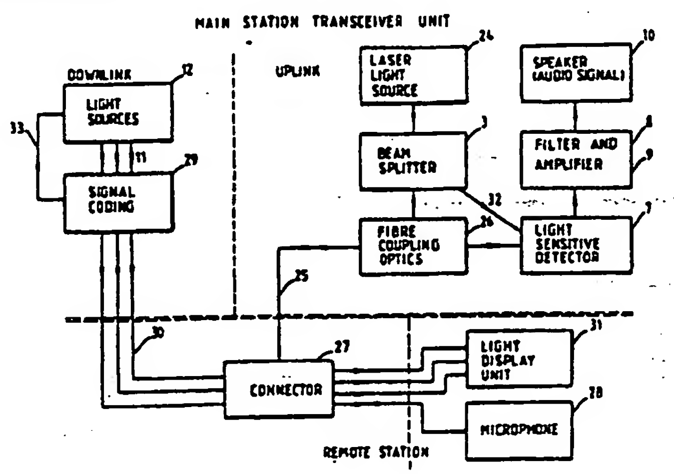
(56) Documents cited by ISA
WO 85/05530 A
CA 1106485 A
Frequenz, volume 32, no. 12, December 1978, pages 356-363

(58) Field of search by ISA
INT CL[4] H04B

(54) Fibre optic communication system for use in hazardous environments

(57) A fibre optic communication system for communication between a main station and a remote station includes a downlink for communication from the main station to the remote station and an uplink to enable to remote station to communicate with the main station. The downlink includes one or more optical sources (12) at the main station to provide one or more light beams (11) which are modulated to carry a signal which is then transmitted to the remote station and displayed. The uplink is formed by modulation at the remote station of a light beam (2) transmitted from a source (24) at the main station, along an optical fibre (25), to the remote station. The modulated beam is transmitted back to the main station and decoded by comparison with unmodulated beam. The communication system has zero or very low magnetic and electrical signatures at the remote station.



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Fibre Optic Communication System for Use in Hazardous Environments.

The invention relates to fibre optic communication systems for use particularly, but not exclusively, for communication between a main station and a remote station where it is desirable for there to be no electrical or magnetic signals at the remote station. Such situations include the communication between a surface ship and a diver or between a control station and a person in a hazardous environment.

Fibre optic communication systems are well known but in all cases electrical signals are involved in converting acoustic signals to optical signals and vice versa. There are, however, some situations where for safety or other reasons, there is a requirement for a communication system with no electrical or magnetic signals within a particular area. In potentially explosive atmospheres the major requirement may be the elimination of the possibility of an electrical spark occuring, while in other situations, such as in the presence of underwater mines, the prime objective may be the elimination of any magnetic signature. For secure speech it is desirable to eliminate any signals that can be intercepted and decoded.

The object of the invention is to provide a system for communicating between a main station and a remote station in which any electrical and magnetic signals at the remote station are minimised and in which the possibility of an electrical spark occurring is eliminated.

The invention provides a two-way optical communications system including:

a) a downlink for transmission from a main station to a remote station; and

b) an uplink for transmission from the remote station to the main station;

wherein the downlink comprises at least one optical source at the main station to provide a light beam, means to modulate the light beam with a signal, an optical fibre for transmission of each modulated light beam from the main station to the remote station, and means to display the signal carried by the light beam at the remote station; and

the uplink comprises at least one light source at the main station for providing a light beam, an optical fibre for transmission of the light beam

from the main station to the remote station, modulation means at the remote station consisting of transducer means responsive to an acoustic signal for modulating the light beam, means to transmit the modulated light beam via the same or a second optical fibre back to the main station, signal processing means at the main station to compare the modulated light beam with the unmodulated light beam and to decode the signal carried by the modulated light, and means to display the signal.

The uplink and downlink light beams may be provided by the same or different optical sources.

The uplink and downlink optical sources, the downlink modulation means and the main station signal processing and display means comprise a main station transceiver unit. The remote station display means and modulation means together comprise a remote station transceiver unit.

Preferably the means to display the uplink signal at the main station comprises means to reproduce the signal acoustically or in some other suitable form. Thus speech at the remote station can be understood at the main station.

Preferably the transducer means at the remote station comprises an optical microphone. The arrangement is such that when a person at the remote station speaks, the microphone modulates the unmodulated light beam received from the main station and the modulated light beam is transmitted back to the transceiver unit at the main station. The transceiver unit at the main station then compares the modulated and unmodulated light and processes the optical signal, decoding it and reproducing it acoustically.

Advantageously the source of the unmodulated light is a laser. Preferably there is provided means to produce a collimated beam of laser illumination. Conveniently a laser diode is used as the light source.

Preferably the optical microphone comprises a light-intensity modulating diaphragm arranged such that the unmodulated input light beam is focussed in the plane of the diaphragm by a lens. The diaphragm is reflective and is preferably silvered. An acoustic signal causes pressure changes at the diaphragm which cause it to move. Any movement of the diaphragm shifts it away from the focal point of the input light beam, thus causing changes in the intensity of the light reflected from the diaphagm as it is moved out of focus. These changes modulate the reflected light beam

which is then transmitted back to the main station. The modulation is a function of the position of the diaphragm relative to the point of focus of the input light beam.

The intensity modulated light beam transmitted back to the main station is focussed on a light sensitive detector. The output signal from the light sensitive detector is connected to one input of a comparator and a signal representative of the intensity of the unmodulated light beam is connected to the second input of the comparator, such that the output from the comparator is a direct analogue of the acoustic signal.

Advantageously the unmodulated beam of light is split by a beam splitter and one part of the beam is then modulated by the acoustic signal, the other part acting as a reference signal. The modulated beam can then be compared to the unmodulated beam and the acoustic signal can be derived from the optical signal.

The beam splitter may be either in the main transceiver unit or in the remote microphone unit. In the preferred arrangement the beam splitter is contained in the main transceiver unit. In this arrangement a single, common fibre may be used to transmit the laser light to the remote station and to return the intensity modulated light which is reflected from the diaphragm back to the main station.

Alternatively the microphone includes two optical fibres placed end to end and arranged such that changes in the alignment of the fibres modulate the optical signal.

The downlink preferably includes an opto-acoustic transducer at the remote station to convert the modulated optical signal sent from the main station into sound so that speech from the main station can be heard at the remote station. A possible opto-acoustic transducer is a simple photophone earpiece.

Where it is difficult to hear the output of an opto-acoustic transducer at the remote station as in a very noisy environment, downlink communication other than by voice can be used. In some cases it may be advantageous to use a simple signalling system of lights instead of an acoustic system. Such a signalling system advantageously comprises one or more light sources at the main transceiver unit each connected via respective optical fibre cables to the remote station. If more than one light source is

used, they are preferably of different colours. In one convenient form, there are three light sources: one green, one yellow and one red. Advantageously information is transmitted to the remote station in the form of colour coded light signals, singly or in combination. For improved recognition the lights are preferably flashed on change of combination.

Advantageously a mechanical shutter is used to set the required light signal combination in the main station transceiver unit. Alternatively electronic switching of the coloured light sources is possible. External electronic controls may also be used to flash the light output on change of combination. Preferably a check of the lights being transmitted is included. This check of the transmitted signal may be made using a beam splitter to reflect some of the transmitted light onto a diffuser which can be viewed by the operator.

The signal displayed at the remote station may be in the form of a light display unit where the lights preferably show up on small, easily visible displays.

Conveniently the fibre is ferrule terminated at the remote station and the transmitted light is transmitted through and internally reflected onto the diffuse face of a right angled prism. This configuration of the unit at the remote station occupies only a very small space.

Preferably super luminescent LEDs provide the sources of light. Each source is advantageously collimated by an aspheric condensing lens and focussed into the corresponding output fibre by means of an achromatic lens.

The ferrule terminations of the fibre optics carrying the respective light signals are fixed into position at the remote station such that each fibre end is adjacent to a side face of a 90° prism of which the other right angled face has a lightly diffusing finish. Light emitted from each fibre is internally reflected from the hypotenuse face onto the diffuse surface.

An alternative system uses an opto-electrical-acoustic earphone to convert optical signals to sound. The sound from such a system can be heard even if the environment at the remote station is noisy. These earphones have very low electrical and magnetic signals and can thus be used at the remote station where it is necessary only to eliminate electrical sparking and/or high electrical signals. This system is not however suitable for use with mines, where the magnetic signature must be as near to zero as possible.

A further possibility for conversion of the optical signal to sound at the remote station is the use of opto-acoustic induction in helium. This could be used in underwater diving applications where helium is used.

Preferably the system configuration is such that the downlink and uplink light beams are transmitted to and from the remote station by means of a fibre optic cable having an appropriate number of optical fibres at its core. This cable could be up to several kilometres long before losses of the signal become such that signal boosting is necessary.

In order that the invention may be more fully understood one embodiment thereof will now be described, by way of example only, with reference to the accompanying drawings of which:

Figure 1 shows the basic elements of a communication uplink for a communication system according to the invention;

Figure 2 shows comparative voltage outputs at points in the communication uplink shown in Figure 1 for an acoustic signal input;

Figure 3 shows the basic elements of a single channel of a communication downlink for the communication system; and

Figure 4 is a schematic block diagram of the configuration of the communication system incorporating the uplink of Figure 1 and the downlink of Figure 3.

Figure 1 shows the basic elements of a communication uplink according to the invention including an optical microphone 1. An input beam of light 2, consisting of a narrow collimated beam of laser illumination, is passed through a 50/50 beam splitting cube 3 and part of the beam 2a is transmitted via an optical fibre (not shown) to the remote station. Here it is focussed in the plane of the microphone diaphragm 1 at 4 by means of a lens 5. Light reflected from the surface of the diaphragm 1 is collected by the lens 5 and transmitted back to the beam splitter 3 at the main station where it is reflected to a second lens 6 which focusses it in the plane of a light sensitive detector 7. The intensity of the light at this point is a function of the position of the diaphragm 1 relative to the point of focus 4 of the input beam 2. The diaphragm must be set up very accurately at the focal point of the light to maximise the intensity changes of the reflected light which are very small. A displacement d of the diaphragm 1 normal to its surface, of

the order of 1um results in a variation of approximately 1% in the level of light detected by the photodetector 7. The electrical signal from the photodetector 7 is passed through a filter 8, amplified by an amplifier 9 and is converted to an audio signal at a speaker 10.

The lens 5 and diaphragm 1 are located within a transceiver at the remote station, while a light source (not shown), the beam splitter 3 and the signal processing electronics are located in a main station transceiver. The light source can be a laser or a laser diode. A laser diode with a power output of the order of 1mW is suitable. It will be obvious that any microphone which converts sound signals to optical signals can be used.

Figure 2 shows the variations in voltage outputs for the system in Figure 1 for changes in pressure at the diaphragm 1. Graph (a) shows the pressure changes at D causing the diaphragm 1 to vibrate in response to a sound signal P(t). The variation in the voltage output from the detector 7 at P about the mean level <V>, the voltage signal from the unmodulated light beam, is a direct analogue of the sound signal at D and is shown in graph (b). The output at P is filtered by the filter 8 to remove the base voltage signal <V> and gives an output at F as shown in Graph (c). This signal is then amplified and converted to sound.

Figure 3 shows the basic elements of a single channel of a downlink which transmits information to the remote station in the form of combinations of colour-coded light signals. Such a downlink is of particular use where the remote station is in a very noisy environment such that hearing the output of an acoustic earphone is very difficult. A single channel can be provided for Morse code or other similar signalling or a simple code of two or more coloured light signals can be used. A versatile but still very simple version has 3 coloured lights of red, yellow and green respectively. In the signalling downlink, a beam of light 11 from a super luminescent LED 12 is collimated by a low f/number (ie about 0.8), collimating, aspheric lens 13. The collimated beam of light is then coupled into the optical fibre 14 by means of an F/2.8 achromatic lens 15.

At the remote station end the fibre 14 is ferrule terminated 16 and the light is transmitted into a side face of a right angle prism 17. The beam is reflected from the hypotenuse face of the prism 17 onto its other side face which has a lightly diffusing surface 18 where it can be viewed.

Mechanical shutters 20 are interposed between the lenses 13 and 15 to shut off the beams 11. Each shutter 20 on the respective channels of the downlink can be used to set the required light signal combination.

The light beam 11 passes through a beam splitter 21 before passing through the optical fibre 14. This reflects some of the transmitted light onto a diffuser 22 which can be viewed by an operator 23. In this way the operator 23 can check the transmitted signal.

The LED 12 can be coloured if required or the light can be passed through a coloured filter (not shown) to provide a coloured light signal. Another system which is not shown in the drawings would be for a single light source to be split into 2 or more beams which are then passed through coloured filters to provide coloured light signals.

Figure 4 shows the configuration of the whole communication system. The uplink (Fig 1) and downlink (Fig 2) light sources, optics and signal processing electronics are included in a main station transceiver unit with optical fibres connected to a remote station transceiver unit. The main station transceiver unit has three main functions:

1) the supply and coding of a light display for a visual downlink, or the supply of a speech modulated light source for an acoustic downlink;
2) the supply of a light source for the uplink microphone;
3) the detection of the intensity modulated light signal derived from the microphone diaphragm and its conversion to an audio signal. This is carried out by the signal processing electronics. The remainder of the electronics drive the LEDs, lasers, laser diodes or other light sources as required.

In the uplink (Fig 1) a laser light source 24 provides the beam of light 2 which is passed through the beam splitter 3. From the beam splitter 3 part of the beam 2 is transmitted down an optical fibre 25 by means of an optical coupling unit 26. The fibre 25 is connected by a connector 27 at the remote station to a microphone unit 28. The microphone unit 28 contains the focussing lens 5, focussing the received light beam 2 on to the diaphragm 1 as shown in Fig 1. The modulated beam reflected from the diaphragm 1 is transmitted back to the main transceiver unit through the optical fibre 25 and is passed together with the unmodulated portion of the beam 32, to the light

sensitive detector 7 where the optical signal is converted to an electrical one. The electrical signal is then passed through a filter 8 and amplifier 9 and is converted to an audio signal by a speaker 10.

Communication from the main station to the remote station is by means of a three channel downlink, one channel of which is shown in Figure 3. Three light sources 12 provide beams of light 11 which are then transmitted or shut off by a signal coding unit 29 to provide a coded light combination signal to the remote station. The signal coding can be achieved by means of mechanical shutters as shown in Fig. 3. Alternatively the light sources could be switched on and off as required. When the signal is changed its noticeability is increased if the light is flashed. This can be done by momentarily increasing the intensity by opening and closing the shutter or by an appropriate switching waveform applied to the light sources. A connection 33 from the signal coding unit 29 can be used to activate electronic switching (not shown) to flash the light source 12 when the shutter 20 (Fig. 3) is opened. Each beam 11 is passed down a respective optical fibre 30 to the remote station via the connector 27. The light combination is displayed on a light display unit 31 which is visible at the remote station.

Thus communication can be carried out between a main station and a remote station where the system at the remote station is totally optical and no electrical or magnetic signals occur.

If a voice downlink is required a photophone earpiece can be used to convert optical signals to sound. The light beam shines onto an absorber medium which produces movement of a diaphragm and hence an acoustic signal. Such a photophone earpiece has been described by Bell Laboratories. The photophone earpiece uses charred cotton fibre as the absorber medium and a laser light source is used to drive the photophone. This may be a Helium-Neon laser or an Argon-ion laser, but is preferably a laser diode.

In situations where low magnetic and/or electrical signals are acceptable an opto-electrical-acoustic earpiece can be used to convert the optical signals to sound at the remote station. Two alternative downlink systems are suitable for use. In the first, a laser beam transmitted from the main station down an optical fibre drives a laser diode at the remote station end. Speaking into the microphone at the main station creates an electrical signal which is used to modulate the light beam which drives the

laser diode. This produces a very low electrical signal which drives a transducer so that the sound can be heard. The second system uses less laser power at the main station and needs a battery power source at the transducer. Because of this, it is not suitable for underwater use, but is useful for surface applications.

A photocell which converts light to emf can be used in an opto-electrical earpiece in either of these systems. The systems consist of a source of speech-modulated light which is transmitted by means of an optical fibre to the opto-electrical earpiece unit. This comprises a conventional electrical earpiece connected to a photodetector to convert light to emf. The photocell may be a silicon photodiode. The most appropriate operating condition of such a diode is photoamperic operation, and a passive system without an amplifier is preferable.

The system can provide secure or safe communications, as it incorporates a totally optical solution at the remote station. For use in diving applications, the use of optical fibres increases the information carrying capacity of the cables thus saving on size and weight. Optical systems have good noise immunity from other signals and are secure from outside interference and interception.

CLAIMS

1. A two-way optical communications system including:

a) a downlink for transmission from a main station to a remote station; and

b) an uplink for transmission from the remote station to the main station;

wherein the downlink comprises at least one optical source 12 at the main station to provide a light beam 11, means 29 to modulate the light beam 11 with a signal, an optical fibre 30 for transmission of each modulated light beam 11 from the main station to the remote station, and means 31 to display the signal carried by the light beam 11 at the remote station; and

the uplink comprises at least one light source 24 at the main station for providing a light beam 2, an optical fibre 25 for transmission of the light beam 2 from the main station to the remote station, modulation means at the remote station consisting of transducer means 28 responsive to an acoustic signal for modulating the light beam 2, means to transmit the modulated light beam via the same or a second optical fibre 25 back to the main station, signal processing means 7 at the main station to compare the modulated light beam with the unmodulated light beam and to decode the signal carried by the modulated light, and means 10 to display the signal.

2. An optical communications system according to claim 1 wherein the means 10 to display the uplink signal at the main station comprises means to reproduce the signal acoustically or in some other suitable form.

3. An optical communications system according to claim 1 or claim 2 wherein the transducer means 28 at the remote station comprises an optical microphone.

4. An optical communications system according to claim 3 wherein the optical microphone 28 comprises a light-intensity modulating diaphragm 1 arranged such that the unmodulated input light beam is focussed in the plane of the diaphragm 1 by a lens 5.

5. An optical communications system according to claim 4 wherein the diaphragm 1 is reflective.

6. An optical communications system according to claim 3 wherein the optical microphone 28 includes two optical fibres placed end to end and arranged such that changes in the alignment of the fibres modulate the input light beam.

7. An optical communications system according to any one of the previous claims wherein the downlink includes an opto-acoustic transducer at the remote station to convert the modulated optical signal sent from the main station into sound.

8. An optical communications system according to claim 7 wherein the opto-acoustic transducer is a photophone earpiece.

9. An optical communications system according to any one of claims 1 to 6 wherein the downlink comprises a signalling system of lights.

10. An optical communications system according to claim 9 wherein the signalling system comprises one or more light sources 12 at the main station unit each connected via respective optical fibre cables 30 to the remote station.

11. An optical communications system according to claim 9 or claim 10 wherein the information is transmitted to the remote station in the form of colour coded light signals, singly or in combination.

12. An optical communications system according to claim 11 wherein the lights 12 are flashed on change of signal.

13. An optical communications system according to any one of claims 1 to 6 wherein the downlink includes an opto-electrical-acoustic earphone to convert optical signals to sound.

14. An optical communications system according to any one of claims 1 to 6 wherein the downlink includes means for conversion of the optical signal to sound at the remote station which uses opto-acoustic induction in helium.

15. An optical communications system according to any one of the previous claims wherein the system configuration is such that the downlink and uplink light beams are transmitted to and from the remote station by means of a fibre optic cable having an appropriate number of optical fibres at its core.

Fig.1

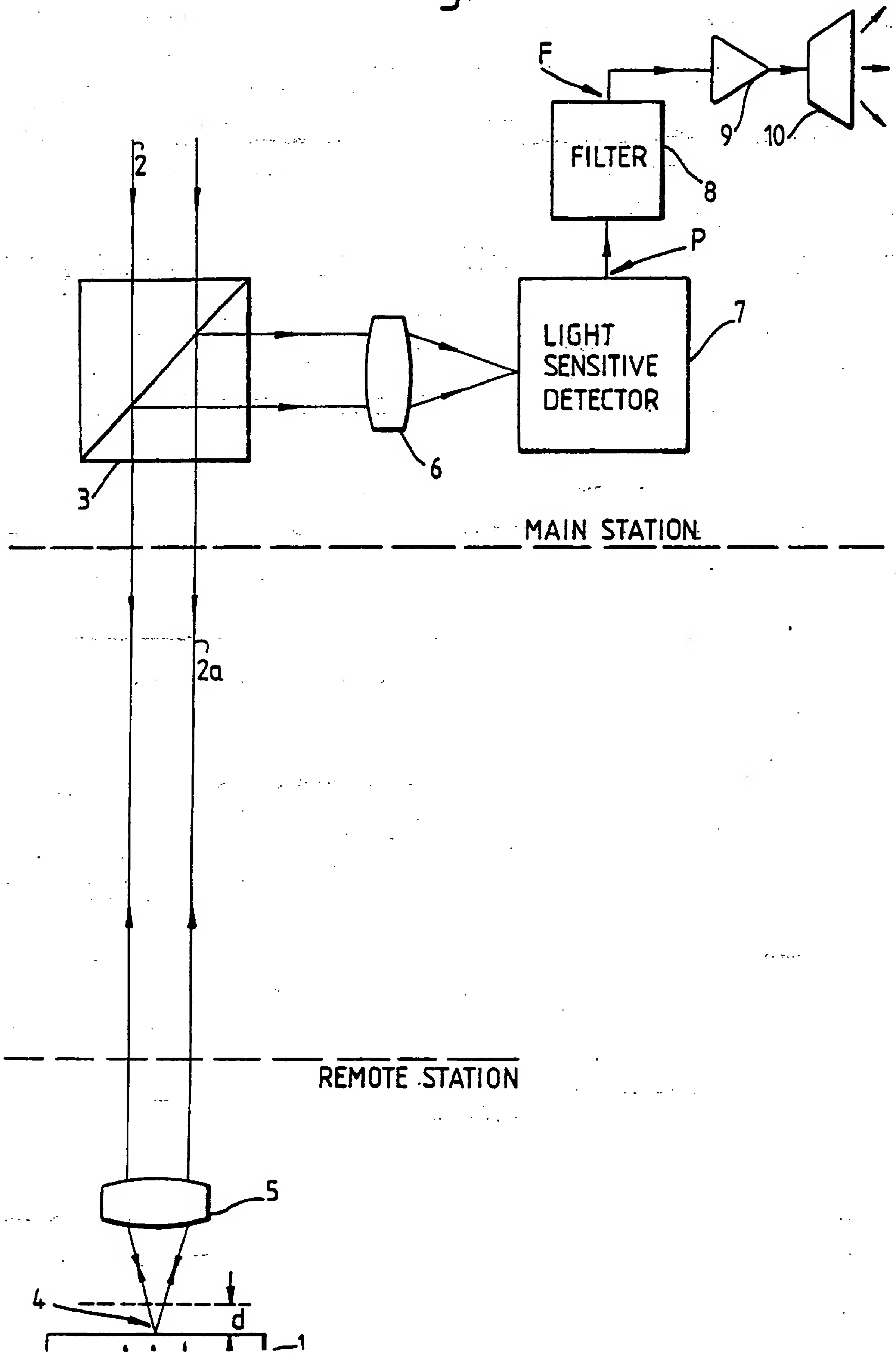

F
FILTER
8
9
10
P
2
LIGHT SENSITIVE DETECTOR
7
6
3
MAIN STATION
2a
REMOTE STATION
5
4
d
1

Fig. 2

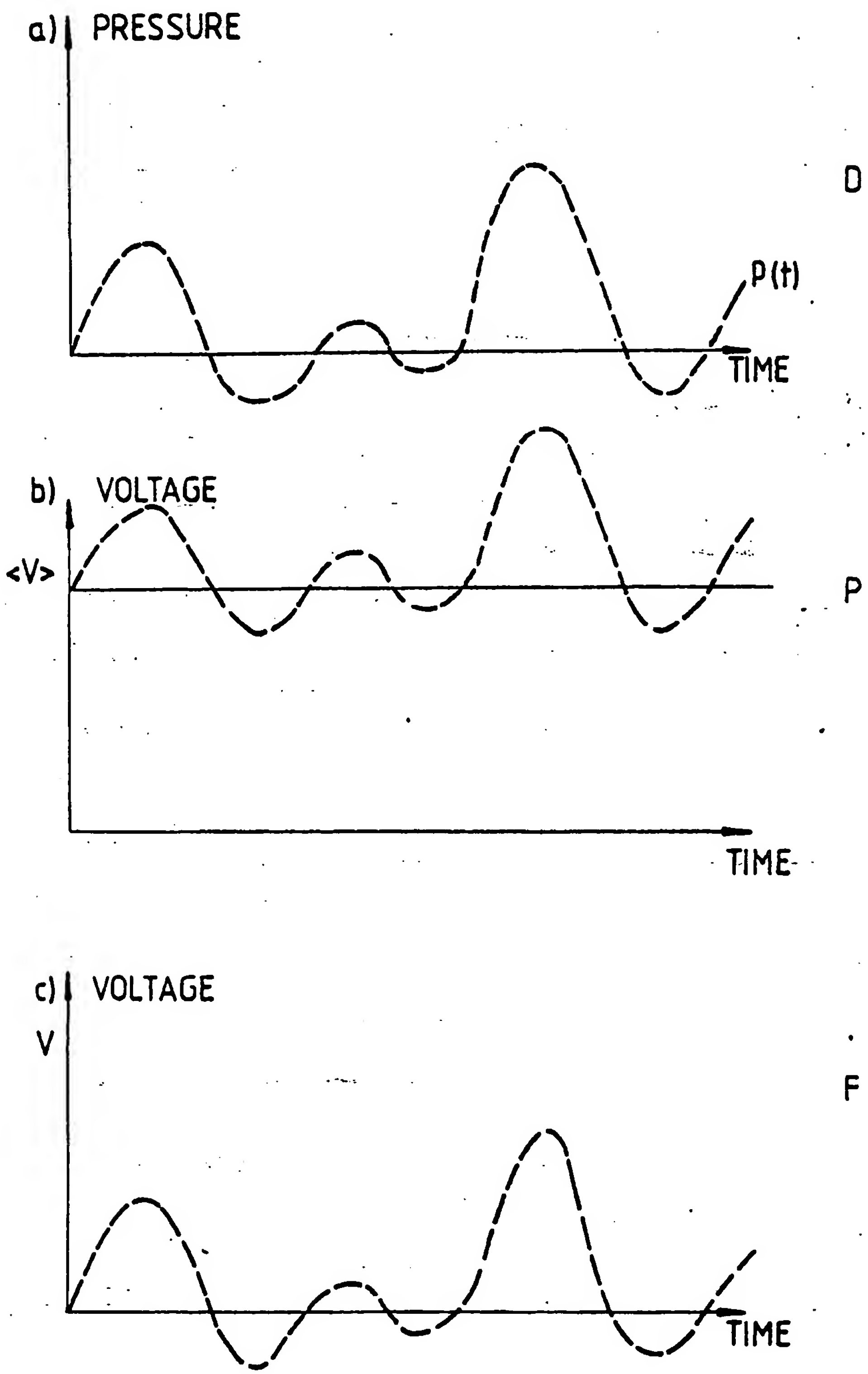
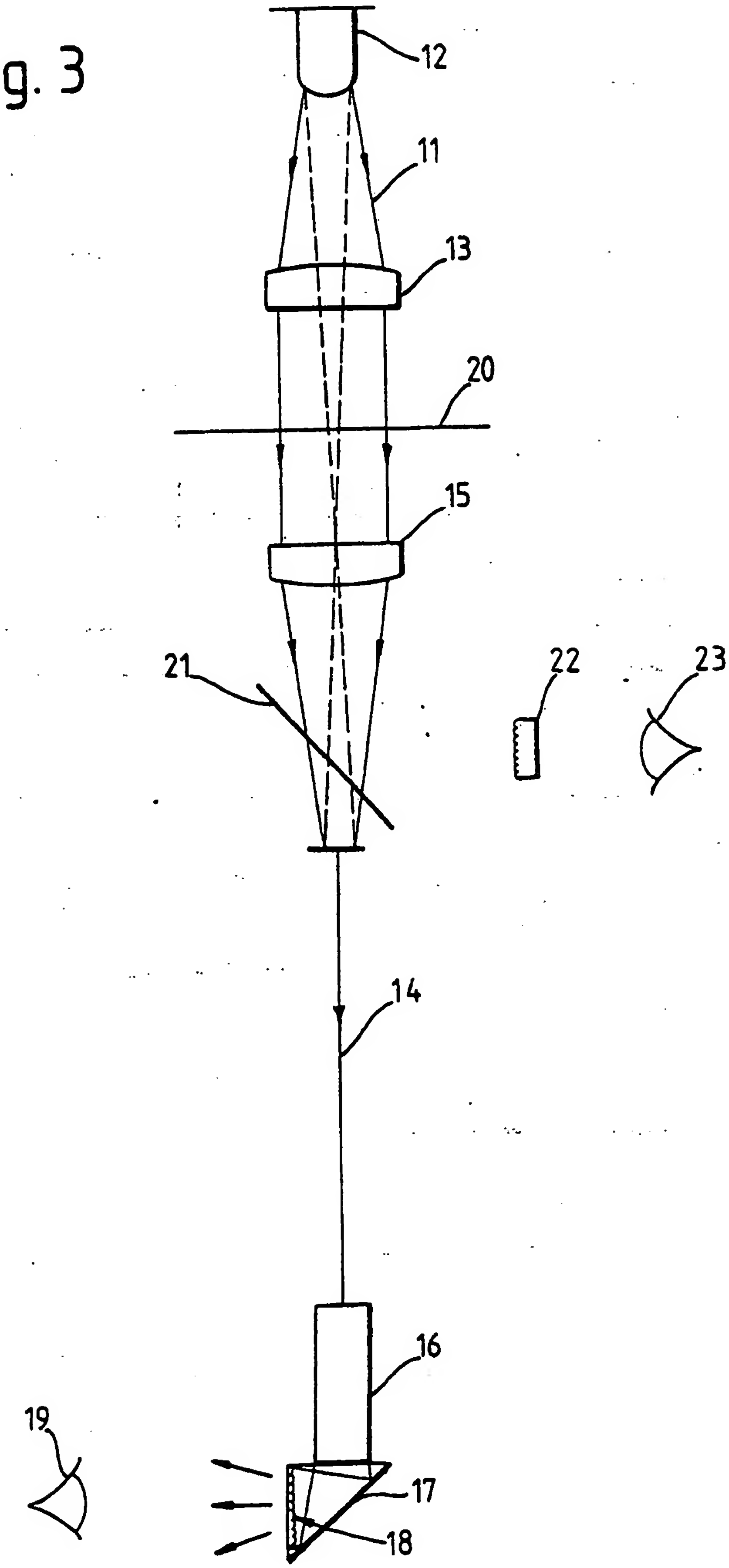


Fig. 3



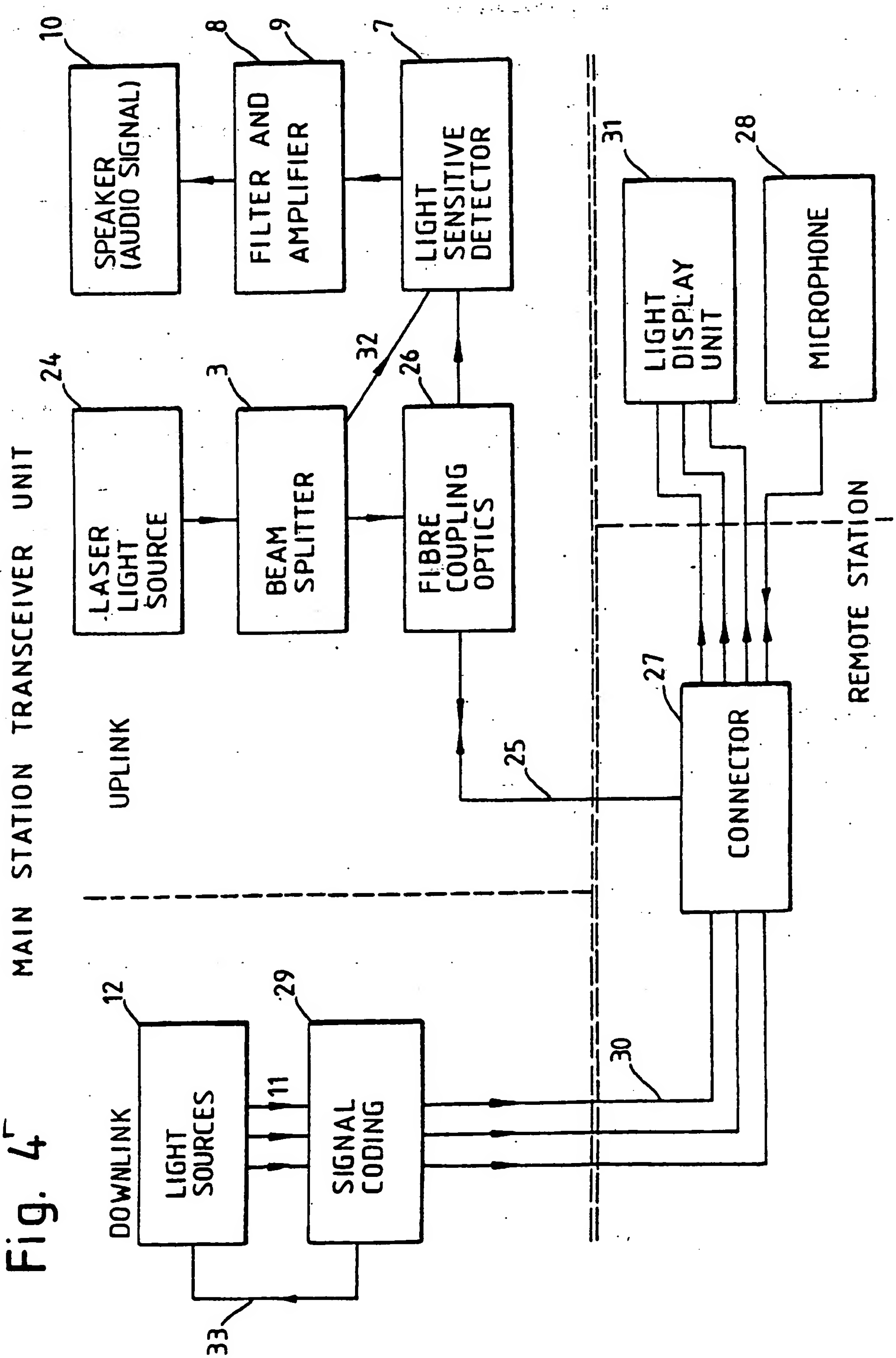

MAIN STATION TRANSCEIVER UNIT
UPLINK
DOWNLINK
REMOTE STATION
SPEAKER (AUDIO SIGNAL)
FILTER AND AMPLIFIER
LIGHT SENSITIVE DETECTOR
LASER LIGHT SOURCE
BEAM SPLITTER
FIBRE COUPLING OPTICS
LIGHT DISPLAY UNIT
MICROPHONE
CONNECTOR
LIGHT SOURCES
SIGNAL CODING
10
8
9
7
24
3
32
26
31
28
27
25
12
29
11
30
33

Fig. 4

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 87/00774

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: H 04 B 9/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	H 04 B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	WO, A, 85/05530 (N.C.R.) 19 December 1985 see page 1, lines 3-18; page 2, line 27 - page 3, line 2; page 3, lines 28-34; page 7, lines 9-25; figure 2	1
A		4,5,9
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Y	CA, A, 1106485 (NORTHERN TELECOM) 4 August 1981 see page 1, line 14 - page 2, line 15; page 3, lines 9-19; page 5, lines 18-21; figure 2	1
A		4-6
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A	Frequenz, volume 32, no. 12, December 1978, (Berlin, DE), I. Fromm: "Optophon - ein optisches Ubertragungssystem für Sprache", pages 356-363 see page 357, left-hand column, lines 34-47; page 357, right-hand column, lines 1-15; page 360, left-hand column, lines 1-16; figures 2,8	1-5,7,8,14
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* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
15th December 1987	22 FEB 1988
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	P.C.G. VAN DER PUTTEN

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 8700774

SA 19245

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 01/02/88
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A- 8505530	19-12-85	EP-A- 0185749	02-07-86
		JP-T- 61502370	16-10-86
CA-A- 1106485	04-08-81	None	

EPO FORM P0479